# MAGNETOMETER RESPIROMETER FOR LABORATORY AND DIVING STUDIES

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SUBMARINE MEDICAL RESEARCH LABORATORY
NAVAL SUBMARINE MEDICAL CENTER MEMORANDUM REPORT NO. 69-4

Bureau of Medicine and Surgery, Navy Department
Research Work Unit MR011.01-5000.01



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## SUMMARY PAGE


### THE PROBLEM

To construct and test a system for the measurement of respiratory tidal volume and respiratory rate that avoids the limitations and disadvantages of the usual mouthpiece, face masks, and neck seals in a plethysmograph.

### FINDINGS

A respirometer based on the use of two pairs of magnetic coils placed on the chest and abdomen, as described by Mead and co-workers, will reproducibly measure tidal volume as well as respiratory rate.

### APPLICATIONS

This system, at its present stage of development, can be used in the laboratory for measurement of tidal volume and respiratory rate when the use of mouthpieces, face masks, and neck seals is undesirable. By the use of a miniature tape recorder and a pressureproof underwater housing, it should be satisfactory for measurement of respiratory rate and tidal volume on SCUBA, Hoka, and hard-hat divers.



ADMINISTRATIVE INFORMATION

This investigation was conducted as part of In-House Work Unit Number MR011.01-5000—Physiological Limits in Saturation-Excursion Diving. The present report is No. 1 on that Work Unit. The manuscript was approved on 16 Jnne 1969 and the Report designated as SubMedResLab Memorandum Report Number 69-4.

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL CENTER

# MAGNETOMETER RESPIROMETER FOR LABORATORY AND DIVING STUDIES

## INTRODUCTION

It has long been the desire of investigators in respiratory physiology to be able to measure tidal volumes and respiratory rates simultaneously without the drawbacks of the standard mouthpieces, face masks, and neck seals in a plethysmograph. This is of special interest for studies in diving physiology to determine respiratory volumes on SCUBA, Hoka, and hard hat divers and to be able to measure changes in lung volumes during breathhold diving. Mead, et al.,[1] recently published the design of a magnetometer respirometer capable of measuring tidal volumes and respiratory rate. This report is concerned with the utilization of this type of equipment, introduction of some modifications, and further development and testing of such a system for laboratory and diving studies. The basic principle involved is that the magnetic field between two coils placed in front and back of the thorax varies according to the distance between the driver coil and the pickup coil which changes during expansion and compression of the chest. This measures not only respiratory rate, but is also essentially proportional to changes in lung volume. The magnetometer described here has some minor modifications of the original design by Mead, et al. Moreover, repetitive tests were performed at various tidal volumes (0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 liters) in sitting and supine positions.

The advantages of this type of a respirometer are three-fold: 1) it need not, in final form with a minature tape recorder, limit the subject's movement and activity significantly; 2) it does not have nearly the degree of conscious awareness and psychological effect on respiration that mouthpieces, masks, and neck seals do; 3) it is reasonably comfortable and therefore suitable for prolonged measurement periods. Its main disadvantage is the requirement of calibration with a water spirometer or other standard for each individual subject each time the magnetometers are placed on the body. This procedure, plus time for calculations and plotting of a calibration curve, requires time. If magnetometers are taped to the chest, shaving of hair may be desirable.

## METHODS

The magnetometers were built from the wiring diagram of Mead, et al.,[1] with the exception of the coils. We used one 54 milli-Henry (mH) coil for the abdominal channel and two 54 mH coils in parallel for the thoracic channel (this gives 27 mH inductance with half the impedance and thus doubles the coil current and doubles the coupling between the driver and pick-up coil). The sensitivity is increased approximately tenfold. Capacitances were doubled (two in parallel in each thorax tank circuit) in the thorax channel to further decrease parallel tank impedance while maintaining the desired frequency. Capacitance values were then chosen to tune tank circuits. However, actual frequencies obtained after tuning were 1111 Hertz (Hz) for abdomen and 1887 Hz for thorax channels.

The coils were held in place by pressure from stretched one-quarter inch internal diameter rubber tubing and tape was used as needed. The positions were as follows: the driving coil of the thoracic pair of coils was at the anterior midline of the chest, nipple level; the pick-up coil was at the posterior midline, nipple level; the abdominal driving coil was on the umbilicus; the abdominal pick-up coil was on the posterior midline at the level of the umbilicus.

The abdominal and thoracic signals were sent into separate amplifiers, and the sum of the outputs was passively put into a third amplifier, with variable attenuation on the thoracic signal for channel balance. The recording required three channels (abdominal component, thoracic component, and summation or tidal volume). Balancing was accomplished by adjusting the summation potentiometer while the subject voluntarily shifts air back and forth from the rib cage to the

abdomen by relaxing and contracting the muscles of the abdominal wall[2]. When balanced properly a line that is straight, or nearly so, will be seen on the summation channel recording the sum of the outputs. This is done with the mouth closed and a noseclip in place; it is an isovolume maneuver and care must be taken to avoid changes due to compression of gas in the chest.

## RESULTS

After several preliminary tests with different coil placement, recording methods, and summation procedures, the procedure described in the methods section was utilized on two subjects. It was decided that the best way to check the accuracy of the magnetometer system was to test its repeatability in a calibration procedure with a water spirometer (Godart Pulmotest). The subjects breathed into the spirometer for eleven breaths—inspirations and expirations—with the magnetometer connected. The subjects attempted to reproduce tidal volumes of 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 liters ambient temperature pressure saturated (ATPS) all eleven times. These values were premarked on the spirometer paper so that the subject could observe each breath as it occurred. Since it was impossible to exactly reproduce a tidal volume, it was decided to utilize the ratio of spirometer volume in milliliters to millimeters deflection of recorder pen for the magnetometer summation for statistical evaluation. This ratio should be identical for breaths of approximately equal size and hopefully nearly equal or at least linear at all tidal volumes from 0.5—3.0 liters. The 3.0 liter volume was not determined on subject RW since it exceeded one-half of his vital capacity of 4.96 liters body temperature pressure saturated (BTPS). This value of one-half of vital capacity was suggested by Mead, et al.,[1] and it appears to be about the limit of volume that can be repeated with accuracy and comfort for the eleven times. Subject BM had a 6-liter vital capacity.

Table I shows a summary of the calibration data for subject BM in the sitting position. Note that the ratios are all in the same order, but not identical. The per cent error represents the standard deviation divided by the mean ratio times 100. It is interesting that the average ratio was 125 for both inspiration and expiration, the average standard deviation was 7.5, yielding a one standard deviation per cent error of 6.0% for both inspiration and expiration.

TABLE I
CALIBRATION OF MAGNETOMETER-RESPIRATOR
SUBJECT BM

| | Nominal Breath Size (liters) | Actual Spirometer Volume (milliliters, mean of 11) | Magnetometer Deflection (mm, mean of 11) | Mean Ratio (ml/mm) | Standard Deviation | % Error |
|---|---|---|---|---|---|---|
| Sitting — Inspiration | 0.5 | 580 | 4.8 | 121 | 7.9 | 6.5 |
| | 1.0 | 1030 | 8.4 | 123 | 7.2 | 5.9 |
| | 1.5 | 1540 | 12.8 | 120 | 6.8 | 5.6 |
| | 2.0 | 2010 | 15.8 | 128 | 6.0 | 4.7 |
| | 2.5 | 2580 | 19.3 | 134 | 7.6 | 5.7 |
| | 3.0 | 3020 | 24.0 | 126 | 9.4 | 7.4 |
| Mean | | | | 125 | 7.5 | 6.0 |
| Sitting — Expiration | 0.5 | 580 | 5.0 | 115 | 5.6 | 4.9 |
| | 1.0 | 1030 | 8.3 | 126 | 7.9 | 6.3 |
| | 1.5 | 1540 | 12.9 | 120 | 8.3 | 7.0 |
| | 2.0 | 2020 | 15.7 | 129 | 6.6 | 5.1 |
| | 2.5 | 2570 | 19.2 | 134 | 7.8 | 5.8 |
| | 3.0 | 3020 | 24.2 | 125 | 8.8 | 7.0 |
| Mean | | | | 125 | 7.5 | 6.0 |

The second table shows both sitting and supine data for subject RW. The average of the mean ratios were equal for inspiration and expiration in each position, though they differed between positions and from subject BM's values. The standard deviation means were almost identical for inspiration and expiration (3.7 and 3.6 sitting; 1.8 and 1.9 supine). Consequently, the mean per cent errors were 4.2% for both inspiration and expiration of the sitting position, and 2.7% and 2.8% respectively for the supine run.

Figures 1 and 2 show calibration curves of magnetometer deflection vs spirometer breath size. The ranges of one standard deviation are plotted on both the ordinate and abscissa; they are calculated on the basis of the one standard deviation per cent error for each ratio and converted back to milliliters volume or millimeters deflection. A conical shaped area shows the range within one standard deviation. The standard deviation increases with breath size, but the per cent errors are fairly random.

**TABLE II**
**CALIBRATION OF MAGNETOMETER-RESPIRATOR**
**SUBJECT RW**

| | Nominal Breath Size (liters) | Actual Spirometer Volume (milliliters, means of 11, ATPS) | Magnetometer Deflection (mm, mean of 11) | Mean Ratio (ml/mm) | Standard Deviation | % Error |
|---|---|---|---|---|---|---|
| Sitting — Inspiration | 0.5 | 550 | 8.1 | 81 | 3.1 | 3.8 |
| | 1.0 | 1080 | 11.8 | 92 | 4.0 | 4.4 |
| | 1.5 | 1630 | 18.3 | 84 | 2.6 | 3.1 |
| | 2.0 | 2040 | 23.1 | 89 | 5.1 | 6.8 |
| | 2.5 | 2620 | 29.4 | 89 | 2.6 | 2.9 |
| Mean | | | | 87 | 3.7 | 4.2 |
| Sitting — Expiration | 0.5 | 550 | 8.3 | 79 | 4.4 | 5.6 |
| | 1.0 | 1080 | 11.7 | 92 | 3.3 | 3.5 |
| | 1.5 | 1530 | 18.1 | 85 | 2.3 | 2.7 |
| | 2.0 | 2060 | 23.0 | 90 | 5.6 | 6.3 |
| | 2.5 | 2630 | 29.3 | 90 | 2.5 | 2.8 |
| Mean | | | | 87 | 3.6 | 4.2 |
| Supine — Inspiration | 0.6 | 630 | 11.5 | 66 | 1.1 | 2.1 |
| | 1.0 | 1060 | 15.7 | 68 | 2.0 | 2.9 |
| | 1.6 | 1600 | 24.4 | 65 | 1.8 | 2.7 |
| | 2.0 | 2020 | 28.8 | 70 | 2.0 | 2.8 |
| | 2.5 | 2510 | 35.6 | 71 | 2.0 | 2.8 |
| Mean | | | | 66 | 1.8 | 2.7 |
| Supine — Expiration | 0.5 | 620 | 11.4 | 55 | 1.6 | 2.8 |
| | 1.0 | 1060 | 15.5 | 68 | 1.6 | 2.2 |
| | 1.5 | 1590 | 24.3 | 66 | 1.3 | 2.0 |
| | 2.0 | 2020 | 28.5 | 71 | 2.9 | 4.0 |
| | 2.5 | 2600 | 36.5 | 71 | 2.1 | 3.0 |
| Mean | | | | 56 | 1.9 | 2.8 |

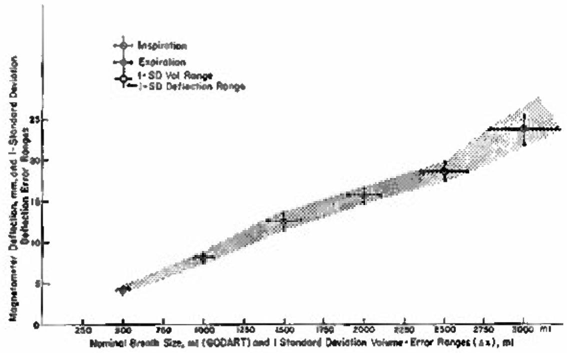


**Fig. 1. Calibration Curves of Magnetometer Deflection vs Spirometer Breath Size, Subject BM.**

## DISCUSSION

It is emphasized that balancing and calibration is done prior to use every time. The thoracic and abdominal outputs must be balanced during the isovolume shifting procedure described earlier. If this is not done properly, a change in relative importance of thoracic and abdominal breathing by the subject will give completely unreliable data. This would likely occur with change in breath size or change in activity. Every time coils are replaced on the subject the apparatus must be rebalanced and new calibration data obtained. The calibration varies according to patient chest size, coil placement, body position, supply voltage, circuit performance, recorder channel balance, and other artifacts. This should be done in a body position as nearly as possible to that likely for the anticipated data collection. If several body positions are used during the experiment, some compromise of accuracy is obviously necessary. Under such circumstances we would suggest a much simpler calibration procedure than described here; perhaps three or four breaths at 0.5, 1.0, and 2.5 liters for normal use. Also, if it is to be used on a diver in the water, the calibration should be done with the subject immersed to the neck level. A discharge of batteries will affect calibration, but good batteries with a proper charge should not affect calibration for a few hours.

We suspect that one reason for the increased accuracy of the supine over the sitting position in subject RW was a tighter coil fit on the skin, resulting in a closer following of the chest movement. Possibly his breathing maneuver was also more reproducible in the supine position. It is recommended to shave off any hair and to use a flexible plastic disc with adhesive on it such as Stomaceal tape for coil attachment. Adhesive tape should be placed on top of the plastic discs. Rubber straps may be required in some cases. In diving studies, a wet suit jacket would help to keep the coils in place. This would give a tighter fit and less rotation of coils than the rubber tubing we utilized. It would also have less psychological and physiological influence on respiration than rubber chest straps.

This instrument has the minor disadvantage of requiring shaving of body hair for best coil attachment and a more important one of somewhat time consuming balancing and calibration procedure. It can be used as described in the present state in the laboratory when mouthpieces and face masks are objectional for any reason. By enclosing it in a waterproof and pressureproof housing with an external balancing control and a miniature tape recorder, it could be used on divers in the water.

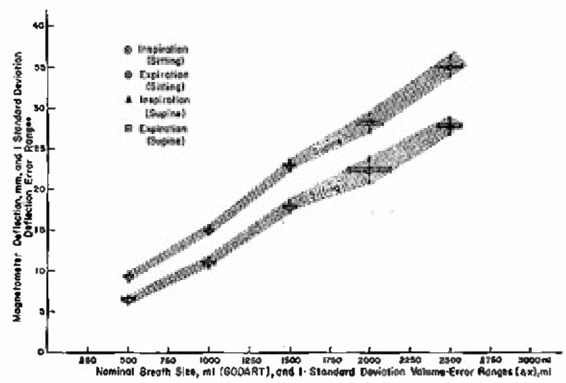


**Fig. 2. Calibration Curves of Magnetometer Deflection vs Spirometer Breath Size, Subject RW.**

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UNCLASSIFIED
Security Classification

# DOCUMENT CONTROL DATA - R & D

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

| | |
|---|---|
| 1. ORIGINATING ACTIVITY *(Corporate author)* NAVAL SUBMARINE MEDICAL CENTER, Submarine Medical Research Laboratory | 2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED<br>2b. GROUP |

3. REPORT TITLE

MAGNETOMETER RESPIROMETER FOR LABORATORY AND DIVING STUDIES

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Interim report

5. AUTHOR(S) *(First name, middle initial, last name)*

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| 6. REPORT DATE | 7a. TOTAL NO. OF PAGES | 7b. NO. OF REFS |
|---|---|---|
| 16 June 1969 | 5 | 2 |

| | |
|---|---|
| 8a. CONTRACT OR GRANT NO. | 9a. ORIGINATOR'S REPORT NUMBER(S) SMRL Memorandum Report Number 69-4 |
| b. PROJECT NO. MR011.01-5000 | |
| c. | 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* |
| d. | |

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

| | |
|---|---|
| 11. SUPPLEMENTARY NOTES | 12. SPONSORING MILITARY ACTIVITY Naval Submarine Medical Center<br>Box 600 Naval Submarine Base<br>Groton, CT. 06340 |

13. ABSTRACT

A system utilizing two pairs of magnets placed on the thorax and abdomen has been constructed and tested. It eliminates the use of mouthpieces, face fasks, and plethysmographic methods for the measurement of respiratory tidal volume and respiratory rate. This is frequently desirable in laboratory studies to eliminate the artifacts produced by the use of the older methods, and with the addition of a miniature tape recorder and pressureproof underwater housing, would allow accurate measurements on SCUBA, Hoka, hard-hat, and breathhold divers. This method provided a 2.7-2.8% one standard deviation error in the supine position and a 4.2% error in the sitting position; the second subject had a 6.0% error while sitting.

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Respirometer | | | | | | |
| Magnetometer | | | | | | |
| Tidal volume | | | | | | |
| Respiratory rate | | | | | | |